The Distribution of Barred Galaxies in the Virgo Cluster

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ABSTRACT

A study of the distribution of barred and nonbarred disk galaxies in the Virgo cluster is presented in an attempt to use the frequency and spatial distribution of galaxies with specific morphological features to study the efficiency of various environmental effects on the evolution of disk galaxies in clusters. The velocity distribution of the barred spirals in the Virgo region is clearly different than that of the nonbarred spirals, suggesting that barred spirals are more common in the main condensation of the cluster. A sample cleansed of galaxies not belonging to the main cluster condensation using the subcluster assignments of Binggeli et al. (1993) bears this out, showing that the radial distribution of barred spirals is more centrally condensed than that of nonbarred spirals. In contrast to the spiral galaxies, the distribution of barred S0 galaxies is statistically indistinguishable from that of nonbarred S0's. Consideration of the level of tidal perturbation due to the cluster mass distribution as compared to that due to individual galaxies suggests that tidal triggering by the cluster mass distribution is the most likely source of the enhanced fraction of barred spirals in the cluster center.

1. Introduction

The galaxies in the cores of present day galaxy clusters are preferentially found to be elliptical and lenticular galaxies, rather than spiral galaxies which predominant in lower density regions of the universe (Gisler 1980; Dressler 1980a). It seems unlikely that this is simply due to different galaxy types forming in different environments, since observations of clusters at redshifts of $z \sim 0.3 - 0.4$ show a much higher percentage of spirals in these clusters than in present day clusters (Couch et al. 1994; Dressler et al. 1994a-b). Apparently some environmental effect is responsible for altering cluster spirals seen at high redshift beyond recognition as spirals by the current day. Several possible mechanisms have been proposed; ram pressure sweeping of the interstellar medium by the gas responsible for the cluster x-ray emission (Gunn & Gott 1972), the cumulative effects of galaxy-galaxy collisions in the dense cluster core (Richstone 1975), or tidal effects due to the gravitational

field of the cluster as a whole (Merritt 1983). Unfortunately to date, it has been difficult to distinguish observationally between the various possible mechanisms.

In a study of the Coma cluster, Thompson (1981) found that the percentage of barred galaxies within approximately 0.75Mpc of the cluster center ($H_0 = 75$km/sec/Mpc and a Virgo cluster distance of 20 Mpc is used throughout this paper) was significantly higher than in the outer parts of the cluster. Thompson noted that this either meant that the excess of barred galaxies represented a kinematically distinct component confined to the core of the cluster, or that bars were triggered by some mechanism as disk galaxies entered the cluster core. If the latter is true, the lifetime of the induced bars must be the less than or the order of the core crossing time; for the Coma cluster the core crossing time is approximately $10^9 yr$, which is around 4–5 disk rotation times for a typical spiral galaxy. Simulations of galaxy-galaxy interactions (Noguchi 1987, 1988) and interactions of a disk galaxy with a cluster gravitational field (Byrd & Valtonen 1990) show that both types of interaction can stimulate the formation of bars in galaxies that would otherwise be stable against the development of a bar, and enhance the formation of bars in galaxies which are already unstable to bar formation (Gerin, Combes & Athanassoula 1990). In his simulations, Noguchi (1988) finds that the lifetime of the induced bars is in the range 5×10^8–$1.5 \times 10^9 yr$. Thus, the frequency of barred galaxies in a given cluster gives information about the interaction history of those galaxies in the recent past (i.e. over the last 3–6 disk revolutions or so). The purpose of this project is to examine the distribution of barred galaxies in the Virgo cluster, as an aid in discriminating between the relative importance of different environmental effects in cluster galaxies.

2. The Virgo Cluster

The proximity of the Virgo cluster gives it a unique advantage over other clusters for the study of cluster galaxy morphology. As Dressler (1980b) has pointed out, in order to do morphological studies at the distance of most clusters requires high quality, high plate scale images taken with large reflectors. The relative nearness of the Virgo cluster means that the morphology of Virgo galaxies can be reliably estimated using more easily accessible Schmidt plates.

In the Virgo cluster region, there exist several kinematically distinct units, not all of which lie at the same distance as the cluster's primary condensation (Tully & Shaya 1984 ; Binggeli, Tammann & Sandage 1987 ; Binggeli, Popescu, & Tammann 1993). In this paper I will generally adopt the definitions and nomenclature for the various substructures given in Binggeli et al. (1993). The primary condensation of the Virgo cluster (the A cluster) is centered near the giant elliptical galaxy M87, and contains the bulk of the elliptical and lenticular galaxies in the cluster. The velocity histogram of the Virgo ellipticals appears

essentially Gaussian (cf. Figure 1), however M87 does not lie at the peak of the velocity distribution for the central galaxies, and is offset from the surface density maximum of the central galaxies as well. Binggeli et al. (1987) argue that this means that the core of the cluster is not in virial equilibrium, since if the mass distribution were centered on the surface density maximum, M87 should be tidally truncated by the cluster core (Merritt1983). The extended x-ray emission seen in the cluster by ROSAT (Böhringer et al. 1994) is centered on M87, suggesting that it does lie at the dynamical center of the cluster.

The B cluster is a spiral dominated structure centered near the elliptical galaxy M49. A determination of the distance to B puts it at the approximately the same distance as cluster A (Binggeli et al. 1993). X-ray emission from cluster B has been detected using the ROSAT all sky survey data (Böhringer et al. 1994), suggesting that even though the B cloud is at the distance of cluster A, it comprises a distinct kinematic unit from A. To the southwest of cluster B lie the W and W′ clouds. The W cloud is at a higher velocity than cluster A, and distance determinations indicate that it probably lies at about twice the distance of A. The W′ cloud lies between B and W on the sky, and also at a distance and recession velocity intermediate between B and W. The M cloud lies to the west of cluster A, and has a distance and redshift approximately twice that of A. Finally, an extended structure lying to the south and at around the distance of A is the aptly named "Southern Extension".

3. The Sample

The initial sample consisted of all galaxies from the Virgo cluster catalog (VCC) of Binggeli, Sandage & Tammann (1985) with total blue apparent magnitudes $B_T \leq 14.0$. Galaxies which had recession velocities $\geq$ 3000km/sec were excluded, since it is unlikely that they are actual members of the Virgo cluster. Morphological types were taken from the *Third Reference Catalogue of Bright Galaxies* (RC3) (de Vaucouleurs et al. (1991)), and the sample was divided into elliptical, lenticular, and spiral + irregular subsamples. The elliptical subsample was retained for fiducial purposes only, since the ellipticals represent a population that define the core regions of the cluster. Galaxies in the disk galaxy (S0 and S+I) subsamples which were viewed to close to edge on were excluded from the sample in order to avoid cases where distinguishing between barred and non-barred morphology is difficult. To determine at what inclination the determination of bar type became difficult, images of barred and non-barred galaxies at various inclinations where examined. From this, it was determined that for galaxies with isophotal axis ratios $R_{25} \geq 2.5$ bar classification became unreliable, so galaxies with axis ratios greater than 2.5 were removed from the

sample. This is also the approximate value above which the fraction of galaxies classified as SAB and SB drops to near zero, confirming that classification of bar types becomes difficult for these more highly inclined galaxies. This separation left a final spiral sample of 32 SA galaxies, 32 SB, and 26 SAB galaxies; and a lenticular sample with 32 S0 galaxies, 24 SB0 galaxies, and 4 SAB0 galaxies.

4. Results

If the Virgo cluster had little substructure, analyzing the distribution of barred versus non-barred galaxies could be done simply by looking at the fraction of different types of galaxies at different radii from the cluster center. This was the approach used by Thompson (1981) to detect the enhancement of the barred galaxy fraction in the center of the Coma cluster. Given the complicated structure of the Virgo cluster, I chose initially to examine the distribution of barred versus non-barred galaxies in velocity space, since most of the substructures are clustered to the high end of the velocity distribution for galaxies in the VCC.

Velocity histograms for the various subsamples are plotted in Figure 1. The histogram for the elliptical galaxies is plotted for comparison, since it is characteristic of galaxies which are confined to the main condensation of the cluster. To formally test the difference between the velocity distribution of galaxies of different bar strength, the Kolmogorov-Smirnov (KS) test, which tests the hypothesis that two samples were drawn from the same underlying distribution, was employed. For the purposes of the KS test, the velocities of SB galaxies were compared to the combined velocities of the SA and SAB galaxies. This was done with the hope that the SB galaxies would represent the population of most strongly and unambiguously barred galaxies, and is also roughly consistent with the sample division used by Thompson for the Coma cluster. The KS test works by finding the maximum difference between the cumulative frequency distribution of the two samples, and then assessing the likelyhood that the difference is due to chance. For the spiral galaxies, maximum deviation between the two samples is because of an excess of barred galaxies with $v_{\odot} \leq 650$ km/sec, and the KS test finds that there is only a 3% probability that this difference is due to chance. Binggeli et al. (1993) have proposed that the velocity range $v_{\odot} \leq 500$km/sec is the only range for the Virgo cluster proper that is uncontaminated by interlopers, which suggests that the difference is due to an enhancement in the fraction of barred galaxies in the A cluster. In contrast to the spiral sample, the KS test finds a 60% probability that the S0 and SB0 galaxies are from the same population.

In order to study the spatial distribution of galaxies in the cluster, a method is needed

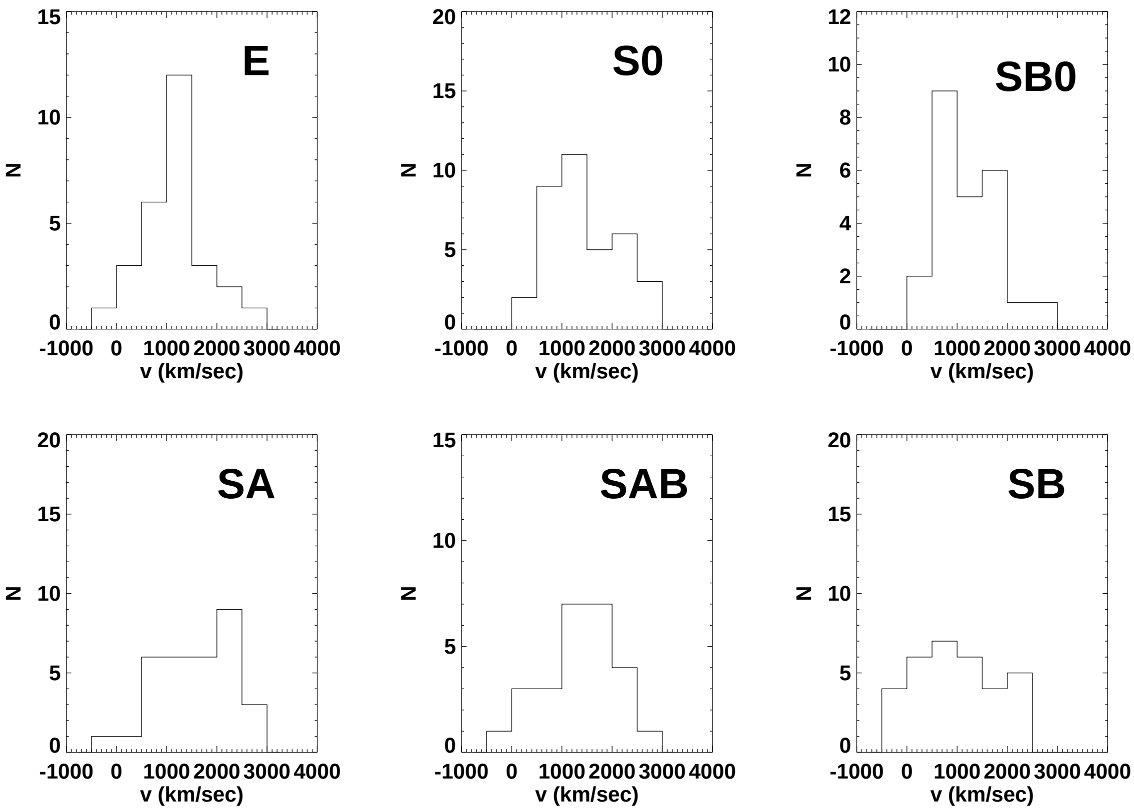
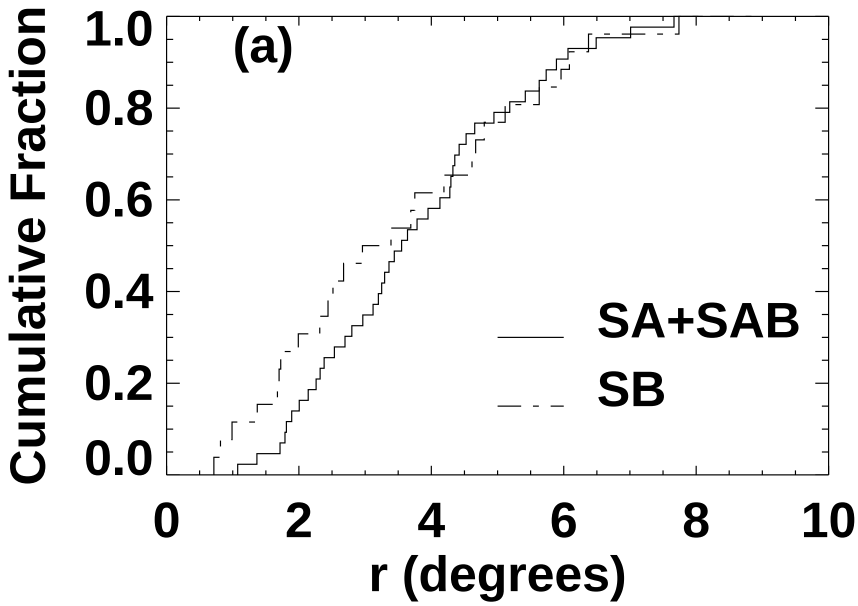


Fig. 1.— Velocity Histograms for galaxy subsamples.



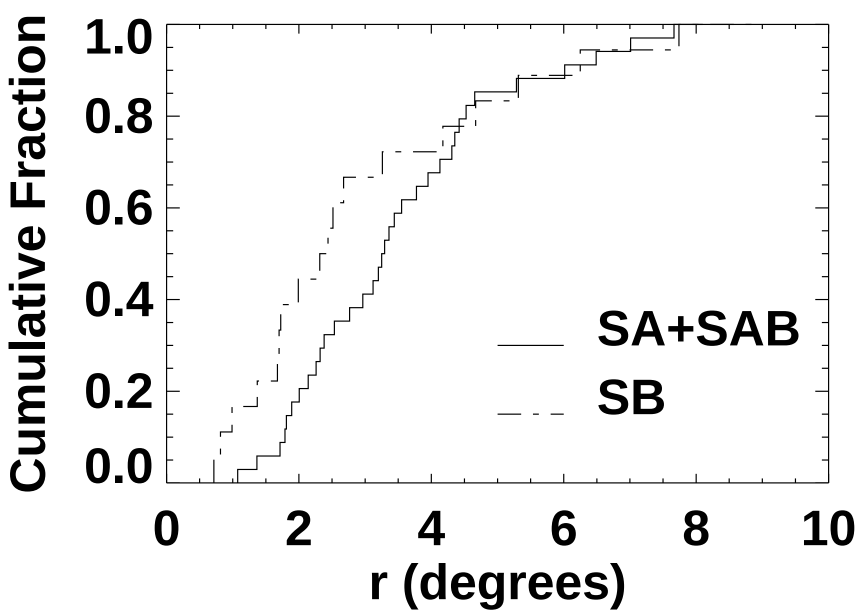


Fig. 2.— Cumulative fraction as a function of radius for SA+SAB and SB galaxies with (a) group B included and (b) excluded.

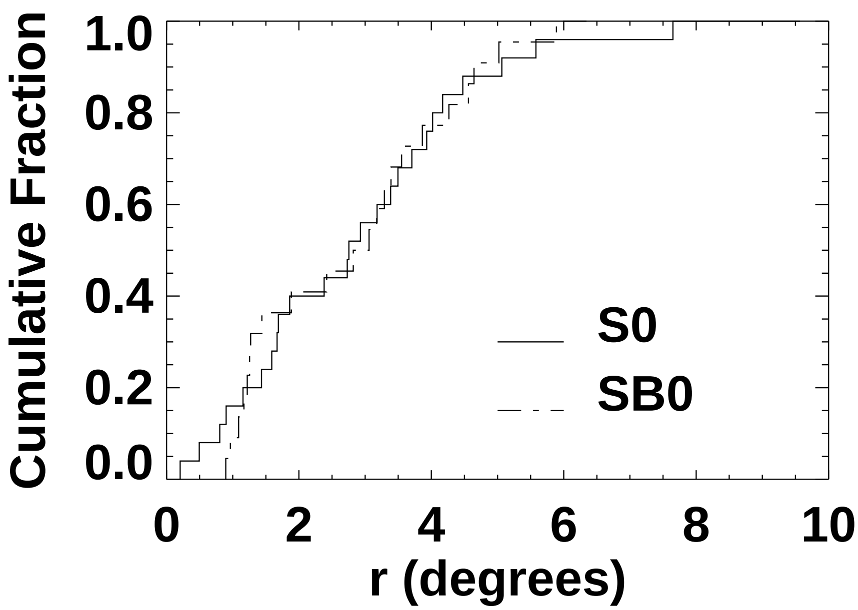


Fig. 3.— Cumulative fraction as a function of radius for the S0 and SB0 galaxies. Only the case with group B included is plotted.

to identify galaxies which are not at the distance of the main condensation and remove them from the sample. Ideally this would be done using a distance indicator that does not depend on the galaxy's recession velocity, such as the Tully-Fisher relation (Tully & Fisher 1977) to determine the distance to each sample galaxy, and remove galaxies that were clearly at a different distance than the cluster. In practice, the lack of the appropriate data, or simply the unsuitability of many sample galaxies (due to unfavorable inclination, peculiarities in structure, etc.) means that this approach is impossible for the current sample. In addition, a purely distance dependent technique would not identify kinematically distinct structures such as the B cluster which lie at a common distance with the main cluster. Therefore, cluster membership was decided based upon the assignments given in Binggeli et al. (1993). The disadvantage of using this method is that the criteria for assigning a galaxy to a particular substructure is somewhat subjective. Whenever possible for the current sample, the assignments have been verified using Tully-Fisher distances, and in every case have found to be accurate.

Using the Binggeli et al. (1993) assignments, all galaxies from the background structures (i.e. groups M, W and W′) as well as the few in the southern extension were excluded from the cluster sample. Whether to exclude galaxies assigned to the group B

is somewhat unclear. On the one hand it is apparently at the distance of group A which suggests that it should be included as belonging to the main cluster. On the other hand, both the redshift and x-ray data indicate that B represents a kinematically distinct unit, suggesting that the environment of the main cluster may not be the primary external effect on component B's galaxies. Keeping this in mind, I analyzed the data for both the case of B included and excluded.

The radial distribution of the cumulative fraction of galaxies with projected radius $\leq r$ for the spiral samples with and without group B galaxies included is shown in Figure 2 (a-b). Both distributions show that the radial distribution of barred spirals is more centrally peaked than that of nonbarred spirals, with the discrepancy being more pronounced for the case where group B galaxies are excluded. The KS test shows that in the case where B is included the two distributions would be drawn from the same parent population 18% of the time. For the case with B excluded, the probability of being drawn from the same population drops to 7%. In either case, the discrepancy between the two samples comes from higher fraction of barred galaxies within 2–2.5° of the cluster center.

The radial distribution of cumulative fraction for the lenticular galaxies in A and B combined is plotted in Figure 3. For the S0 galaxies the case with group B excluded was not examined separately, since the small number of lenticulars assigned to B (5) has a negligible effect on the radial distributions. Unlike the case for the spirals, the radial distribution of S0 and SB0 galaxies appear to be identical. The KS test agrees with this qualitative impression, giving a 60% probability that the S0's andf SB0's are drawn from the same parent population.

5. Discussion

It seems likely that the increased fraction of barred spirals in the center of both the Virgo and Coma clusters is due to these galaxies suffering strong tidal interactions in the inner parts of the cluster. Three immediate possibilities present themselves for how the bars are formed; (1) Tidal triggering due to the gravitational field of the cluster, (2) tidal triggering due to encounters between individual galaxies in the cluster, and (3) Thompson (1980) suggested that tidal stripping of the galaxies' dark matter halo would lead to a puffing up of the remaining halo; the reduced central mass density in the galaxy may then leave the galaxy disk unstable to spontaneous bar formation (Ostriker & Peebles 1973). However Byrd & Valtonen (1990) find that a bar is induced in a galaxy long before significant stripping occurs. For this reason I will not consider the third mechanism in the following discussion. The question then becomes whether the tidal effects are due to the

concentrated mass of the cluster itself, or due to an enhancement of the galaxy–galaxy interaction rate because of the increased galaxy density in the cluster core. It is not possible to use detailed considerations to address this subject at present. Although simulations exist that demonstrate both types of interactions are capable of inducing bars in some circumstances, many parameters play a role in determining whether a bar is formed or not (perturbation strength, ratio of halo (or bulge) to disk mass, sense of encounter with respect to disk rotation axis (prograde or retrograde)), and the extensive grids of models that would delineate the regions of parameter space where interactions do and don't lead to bar formation do not exist. The best it is possible to do at present is to use the existing models to point out gross results as to what parameter values seem to control bar formation in a given interaction.

In their simulations of the formation of ocular spirals, Elmegreen et al. (1991) characterize the strength of the perturbation using the parameter S which is ratio of the change of momentum due to the perturbation to the initial momentum for a particle at the outer edge of the galaxy. Elmegreen et al. found bars were formed in their simulations only if the value of S exceeded a threshold value, showing that for a given galaxy, the strength of the perturbation is a controlling factor in whether a bar is formed or not.

The utility of S in estimating perturbation strengths for observed galaxies is not great however, since it depends on the ratio of the timescale over which the perturbation acts to the orbital timescale of a star in the outer part of the galaxy's disk, making S difficult to derive from observations. For this reason, it is common to use a parameter which isolates those quantities which are more easily derived from observations, such as masses and distances. Byrd & Valtonen (1990) define the parameter P, which for an arbitrary mass distribution on the part of the perturber depends on the local gradient of the gravitational force due to the perturber ∇f as $P = \nabla f r_g^3/(GM_g)$, where r_g is the optical radius of the galaxy, and M_g is the mass of the galaxy within the optical radius. For a point mass perturber this simplifies to $P = (M_p/M_g)(r_g/r_p)^3$. As in the simulations of Elmegreen et al., bars are formed in Byrd & Valtonens simulations only when the perturbation level (measured using P in this case) exceeds some threshold level, generally in the range 0.006–0.1, where the lower value is for a disk with no massive halo, and the upper value for the case where the halo mass dominates the total galaxy mass ($M_{halo}/M_{disk} \gtrsim 2$).

The self gravity of a galaxy's disk is important in determining whether a bar is formed or not (Noguchi 1987). This means that the lower the ratio of disk to halo (or bulge) mass, the more stable a galaxy will be against bar formation (Ostriker & Peebles 1973). Mihos & Hernquist (1994) have simulated interactions using galaxies with dense bulges and galaxies with no bulge component. They find that the presence of a sufficiently dense bulge does

indeed inhibit the formation of a bar in cases where a strong bar is formed in the case of a pure disk galaxy.

Encounters that occur with too high a velocity should have little effect on the structure of galaxy disks, since the impulsive force on disks stars is small because of the short duration of the interaction. Retrograde encounters are less effective than prograde encounters in affecting the structure of disk galaxies for the same reason; in the rest frame of disk stars, the combination of disk rotation velocity plus encounter velocity means that a star sees the tidal impulse for only a relatively short time. For a given galaxy then, a minimum level of perturbation is necessary to induce bar formation, modified by the details of the galaxy and encounter. In this way, a certain level of perturbation is a necessary but not sufficient condition for a bar to be induced.

In an attempt to determine whether barred spirals in Virgo where more likely to be interacting with other galaxies more often than nonbarred cluster spirals, the VCC was searched down to a limiting magnitude of $B_T = 18.0$, the nominal completeness limit of the catalog, to identify the nearest neighbor for each spiral in the main cluster. Galaxies which were identified as non-cluster members in Binggeli et al. (1993) were rejected from consideration. Galaxies near the center tend to have closer nearest neighbors than galaxies at greater radius, simply due to the increase in galaxy surface density near the cluster center. In order to remove this effect the local surface density near each galaxy was evaluated using the surface density fit to the VCC data given in Ferguson & Sandage (1990). The local surface density ρ was then used to calculate the expected distance to the nearest neighbor assuming a Poisson random distribution distribution of galaxies $d_{Poiss} \approx (2\sqrt{\rho})^{-1}$ (see e.g. Keel & van Soest 1992) . Although the assumption of a random distribution is not strictly correct since the surface density varies with radius, the fact that core radius of the fit distribution of 1.4° is much larger than even the greatest nearest neighbor separation means that on the scales being considered, the surface density is close to constant so that the assumption used to find the expected nearest neighbor distance is valid.

The ratio of the measured nearest neighbor distance to d_{Poiss} is plotted against the radius in Figure 4. Two results are noteworthy from this graph; first, as an ensemble the SB spirals are no more likely to have a nearer neighbor than SA and SAB spirals, and second, there is no tendency for galaxies near the center of the cluster, the region of increased bar fraction, to have nearby companions. It is important to note that although the nearest neighbor analysis shows that the barred cluster spirals do not preferentially have nearby companions, it does not demonstrate unambiguously that galaxy–galaxy interactions is not a viable mechanism for stimulating bar formation. The high density and relative velocities of the galaxies in the clusters core means that in an unbound encounter, the time spent

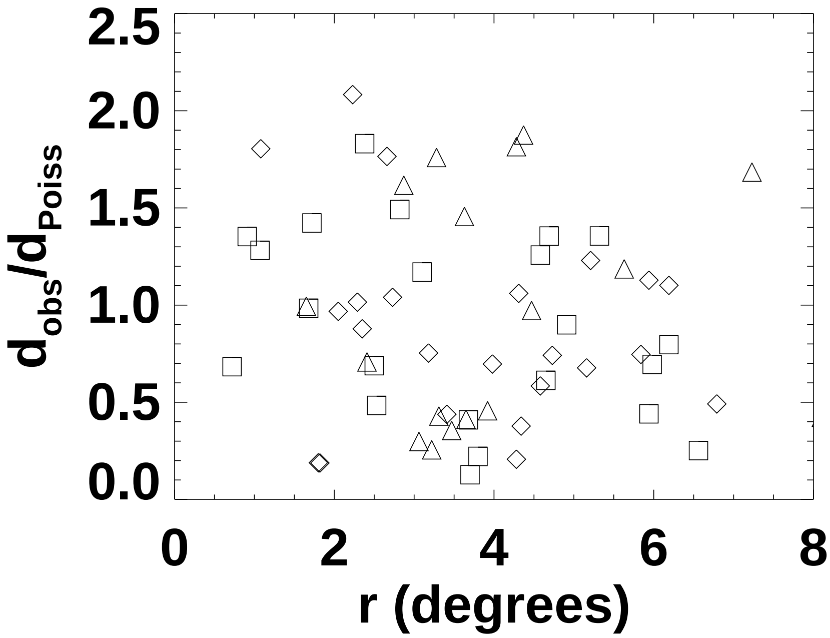


Fig. 4.— Ratio of observed nearest neighbor distance to expected distance given the local surface density, plotted against cluster–centric radius. SB spirals are plotted as squares, SAB as triangles, and SA as diamonds.

within d_{Poiss} by the perturbing galaxy is much shorter than the lifetime of the bar.

What really is needed then is a measure of the efficiency of galaxy collisions in the inner parts of the cluster for stimulating bars. In specific, a measure of how likely a bar inducing collision is for a single crossing of the cluster core. If the expected time between bar inducing collisions is of the order of the core crossing time then collisions may be able to compete effectively with cluster tides in the formation of bars, if the collision time is much longer than the crossing time then cluster tides should dominate. For a region of linear dimension d with a galaxy density n, each with a cross section σ for bar forming collisions, a galaxy traveling at a velocity v will have collision and crossing times of $t_{coll} = 1/n\sigma v$ and $t_{cross} = d/v$, so the ratio of the two times is just

$$t_{cross}t_{coll}^{-1} = n\sigma d. \tag{1}$$

If an induced bar has a lifetime that is much longer than the orbital time scale of the galaxy in the cluster, the chance of forming a bar depends not only on $t_{cross}t_{coll}^{-1}$, but on the

number of times the galaxy has crossed the cluster core. That is, if the galaxy has crossed the core N times, galaxy-galaxy collisions will be efficient at forming bars if

$$t_{cross}t_{coll}^{-1} \gtrsim N. \tag{2}$$

The fact that $\sim 2/3$ of spiral galaxies are of type SB or SAB may imply that in general bars in galaxies are long lived phenomena. On the other hand, there are indications that collisionally induced bars may not always be long lived. In his simulations of bar inducing interactions, Noguchi (1988) finds that the bars have lifetimes on the order of 4–6 disk rotations. The dissolution of the bar in these simulations coincides with the time it takes for gas clouds comprising a few percent of the galaxies initial disk mass to make it into the inner parts of the galaxy. Simulations by Norman, Sellwood, & Hasan (1995) to explore the effect of increasing the central mass concentration in models which contain a strong, self-consistent bar show that accumulation of $\sim 5\%$ of the initial disk mass in the galaxy core leads to rapid dissolution of the bar. The remnants of the bar end up in a distribution similar to a galactic bulge. Although they do not follow the galaxies in their simulations to bar dissolution, Byrd & Valtonen(1990) see large mass inflows into the central 1kpc of their galaxies, suggesting that the lifetime of the bars in their simulations may also be limited. For this reason the following discussion will assume that whatever mechanism triggers the bar formation in the cluster galaxies must operate efficiently over a single core crossing.

If for the purposes of this argument we consider a galaxy on a radial orbit through the cluster, then the average density within a radius $d/2$ of the center of the cluster can be obtained using the density profile from Ferguson & Sandage (1990). Doing this, the ratio of time scales becomes

$$t_{cross}t_{coll}^{-1} = 6n_{\circ}\sigma r_c f(d/2r_c), \tag{3}$$

where $n_{\circ} = 175\text{galaxies/Mpc}^3$ is the central density of galaxies brighter than $B_T = 14.0$, $r_c = 489\text{kpc}$ is the core radius of the density distribution (for a Virgo distance of 20 Mpc), and the function f is $f(x) = (\ln(x + (x^2+1)^{1/2}) - x/(x^2+1)^{1/2})/x^2$. A radial orbit was selected not only for computational simplicity, but also because it will maximize the value of $t_{cross}t_{coll}^{-1}$ since it probes the highest density regions of the cluster.

The condition for collisional excitation of bars to be an effective process is then for the cross section for bar formation to be high enough that $t_{cross}t_{coll}^{-1} \gtrsim 1$. The cross section may be related to the perturbation strength P by assuming that the cross section is related to the impact parameter b as $\sigma = \pi b^2$. If we assume that the colliding galaxies are of equal mass, then $P = (r/b)^3$ where r is the optical radius of the galaxy. In their study of cluster tidal effects, Byrd & Valtonen (1990) find that triggering occurs at perturbation levels in the range $0.006 \leq P \leq 0.1$, where the lowest value is associated with systems with little or no dark matter halo, while the higher value is for systems with halo masses greater than

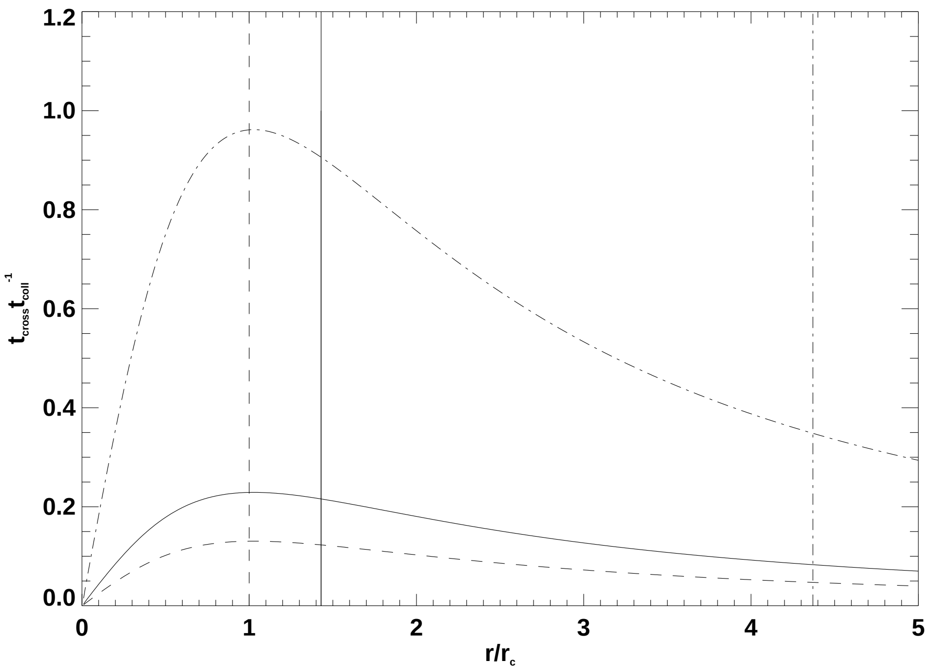


Fig. 5.— $t_{cross}t_{coll}^{-1}$ vs. radius for different perturbation levels. The vertical lines give the radius within which the cluster mass gives the level of perturbation for which the curves were calculated.

about two times the disk mass. Figure 5 shows the ratio of time scales plotted against radius for three different values of P, where the cross section has been derived for a galaxy radius of 10 kpc. The vertical lines are the radius at which the perturbation strength due to the cluster mass is the same as that for the curve of $t_{cross}t_{coll}^{-1}$ plotted with the same line style. The dashed line is for $P = 0.1$ showing that if cluster galaxies have a significant dark halo, galaxy-galaxy collisions should not be an efficient bar stimulating mechanism. The solid lines are for a value of $P = 0.043$, which was chosen because it was the perturbation level due to the cluster at the radius within which there is an enhanced bar fraction, in this case within $2^{\circ} = 700$kpc. Again in this case, $t_{cross}t_{coll}^{-1}$ is still significantly less than 1. Finally, the dashed–dot line is plotted for a value of $P = 0.005$, which is comparable to Byrd & Valtonen's lowest triggering level, and was selected since it gives $t_{cross}t_{coll}^{-1} \approx 1$ at a core radius. Although this condition does raise $t_{cross}t_{coll}^{-1}$ near the center, it also makes the region over which the cluster reaches the same triggering level over 2 Mpc in radius, much larger than the region of enhancement that is actually observed. Although the above arguments do not establish unambiguously that cluster tidal interactions are the dominant mechanism, they are at least strongly suggestive that this is the case.

Whether cluster tides or galaxy-galaxy interactions is the responsible mechanism for inducing bars, the fact that a triggered bar may only persist for a few disk rotations suggests the interesting possibility that a single galaxy may undergo repeated episodes of bar formation and dissolution each time it orbits through the cluster core. Since the bar remnants form a structure similar to a galaxy bulge (Norman et al. 1995), this may be a mechanism by which the morphology–density relation (Gisler 1980; Dressler 1980a) arises. While this is clearly speculative at this point, the possibility definitely warrants further investigation.

5.1. Comparison with the Coma Cluster

The increased fraction of barred spirals in the core of the Virgo cluster is in qualitative accordance with Thompson's finding for the Coma cluster, however a more detailed comparison between the results for the two clusters is instructive. The cluster–centric radius over which there is an enhancement in bar fraction is essentially the same for both clusters, around 0.75Mpc. This is somewhat puzzling if the cluster mass is inducing the bars, since Coma is more massive than Virgo, so that a given level of perturbation should occur at a greater radius in Coma than in Virgo. Using the mass determination for Coma given in Hughes (1989), there is 2.67 times as much enclosed mass within 0.75Mpc as in Virgo. This means that a galaxy in Coma will feel a level of perturbation corresponding to that felt in Virgo at a radius of 0.75Mpc at a radius of $\sim$ 1.2Mpc. Given the limited sample sizes, the uncertainties in the extent over which there is an enhancement in bar fraction are probably large enough that this discrepancy is not highly significant. Careful study of several more nearby clusters will be necessary to test whether this difference is meaningful.

Unlike in Coma, where the fraction of SB0 galaxies is also higher in the cluster center, Virgo shows no such enhancement. This difference could potentially be due to the relatively higher mass of the Coma cluster. Since a massive central spheroidal component in a galaxy can help stabilize a galaxy against bar formation, a larger perturbation is required than for a galaxy with a smaller bulge. Given that S0's have more massive bulges than intermediate and late type spirals (Simien & de Vaucouleurs 1986), it should be more difficult to trigger bar formation in S0 disks than in the disks of spirals. Perhaps we are seeing a case where the mass concentration in Virgo is large enough to trigger bars in spirals but not S0 galaxies, while Coma's greater mass may be able to trigger bars in both spirals and S0's. This result is also speculative with the current data, analysis of more clusters may also be helpful in examining this point more thoroughly.

6. Conclusions

A study of the velocity distribution of disk galaxies in the Virgo cluster region has been carried out, with the result that velocity distribution of barred spirals is skewed to lower recession velocities when compared to weakly or unbarred spirals. Since galaxies with low velocities in the Virgo region are preferentially associated with the main condensation of the Virgo cluster, this suggests the difference in the velocity distribution for spirals of different bar strength is due to an increase in the fraction of barred spirals associated with the main cluster when compared to less dense structures in the region.

Isolation of galaxies which belong to Virgo's main condensation indicate that the radial distribution of SB galaxies is more centrally peaked than that of the SA and SAB galaxies. Furthermore, there is no indication that barred spirals have more nearby companions than do unbarred spirals. Although the lack of nearby companions by itself does not exclude the possibility that galaxy-galaxy interactions are the dominant bar triggering mechanism, the fact that the ratio of crossing to collision times is much less than unity for reasonable perturbation strengths suggests that galaxy collisions are not efficient enough to be responsible for the increased bar fraction. The inference from these results is that the central concentration of barred galaxies is due to triggering of bars by the cluster mass distribution, as suggested by the simulations of Byrd & Valtonen (1990).

Unlike the spiral galaxies, the S0 and SB0 galaxies in Virgo have velocity and spatial distributions that are indistinguishable from one another. It is speculated that the difference between the spiral and lenticular galaxies may be due to the cluster tidal forces being insufficient to over come the stabilizing effect of the S0's more massive central bulges. Taken together, the enhanced fraction of barred galaxies in the center of the Virgo and Coma clusters is compelling evidence for the importance of tidal interactions in the evolution of cluster galaxies.

A careful reading of an earlier draft of this paper by Bill Keel resulted in significant improvement in its presentation.

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